Solar Energy Materials and Solar Cells 176 (2018) 134–141

Contents lists available at ScienceDirect

Solar Energy Materials and Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Environmental stability of transparent and conducting ITO thin films coated on flexible FEP and Kapton® substrates for spacecraft applications

K.P. Sibin[a,c], A. Carmel Mary Esther[b], H.D. Shashikala[c], Arjun Dey[b], N. Sridhara[b], Anand Kumar Sharma[b], Harish C. Barshilia[a,*]

[a] *Nanomaterials Research Laboratory, Surface Engineering Division, CSIR-National Aerospace Laboratories, Bangalore 560 017, India*
[b] *ISRO Satellite Centre, Bangalore 560 017, India*
[c] *Department of Physics, National Institute of Technology Karnataka, Surathkal, Mangalore 575 025, India*

A R T I C L E I N F O

Keywords:
ITO thin film
Sputtering
Space environment studies
FEP
Kapton®
Plasma etching

A B S T R A C T

Acquiring good adhesion of ITO thin films on polymer substrate is a major concern, especially for space related applications. Delamination of ITO coating on these polymers can seriously damage the spacecraft. This paper presents the development of highly transparent and conducting ITO thin films on as-received and surface treated fluorinated ethylene propylene (FEP) and Kapton® substrates by reactive direct current magnetron sputtering. Stability of the ITO coating on FEP and Kapton® substrates was studied in simulated space environments. Environmental tests such as: relative humidity, thermal cycling and thermo vacuum were performed. Thermo-optical properties and sheet resistance of ITO coated FEP and Kapton® substrates were studied before and after environmental tests. Optimized ITO coating with thickness of ~ 15 nm on FEP and Kapton® substrates showed sheet resistance in the range of 2–4 kΩ/sq. with high average transmittance and high IR emittance. Adhesion of ITO coating on FEP substrate was improved by Ar plasma etching. X-ray photoelectron spectroscopy and field emission scanning electron microscopic studies of etched FEP substrate showed defluorination and high roughness of the etched surface which helped for better adhesion of ITO coating. We demonstrated that ITO coated plasma etched FEP substrate showed no change in the sheet resistance and thermo-optical properties. Moreover, ITO coated etched FEP substrate showed good environmental stability than ITO coated untreated FEP substrates.

1. Introduction

Thermal control system in spacecraft applications has very crucial role to protect the inner components from the temperature gradients in space [1–4]. For better performance and reliability of the electronics and other components inside the satellites a steady temperature environment has to be maintained [1]. However, in space due to the lack of any medium around the satellite other than radiation; there are no other conventional heat transfer methods possible to transfer heat from inside of the satellite to the outer space. Therefore, passive thermal control elements such as Kapton® based multilayer insulation (MLI) blanket, rigid and flexible optical solar reflectors, etc. are used to control the outer and inner temperature of spacecraft. The abundantly used outer surface materials for thermal control in space are fluorinated ethylene propylene (FEP) and polyamide Kapton® [1,4–8]. FEP and Kapton® substrates have good thermal stability and space environment resistance especially for spacecraft operating temperatures [5,8,9]. Owing to the high thermal emittance and high transmittance, FEP is an excellent candidate for the flexible optical solar reflector (FOSR) application [10–12]. Rear side Ag coated FEP substrate shows the lowest α/ε value (where α is absorptance and ε is emittance), therefore, the equilibrium temperature will be low on the surface [2,13,14]. On the other hand, highly reflective rear surface aluminized Kapton® is often used in MLI (implemented for thermal insulation purpose) as outer surface (i.e., space facing surface). It is well known that, space environment frequently alters depending on altitude and sun seasons [15]. The major space environment variables are temperature, low dense atoms and molecules, electron clouds with different energies, charged particles, plasmas, atomic oxygen, etc. The concentrations of these variables also depend on altitude and type of orbit. In particular, for communication satellites in geostationary orbit, the presence of energetic electrons is the major concern. Aforesaid thermal insulation materials based on FEP and Kapton® are able to withstand most of the space environment but not for electrostatic charges because of their

* Corresponding author.
E-mail address: harish@nal.res.in (H.C. Barshilia).

https://doi.org/10.1016/j.solmat.2017.11.024
Received 17 July 2017; Received in revised form 26 October 2017; Accepted 14 November 2017

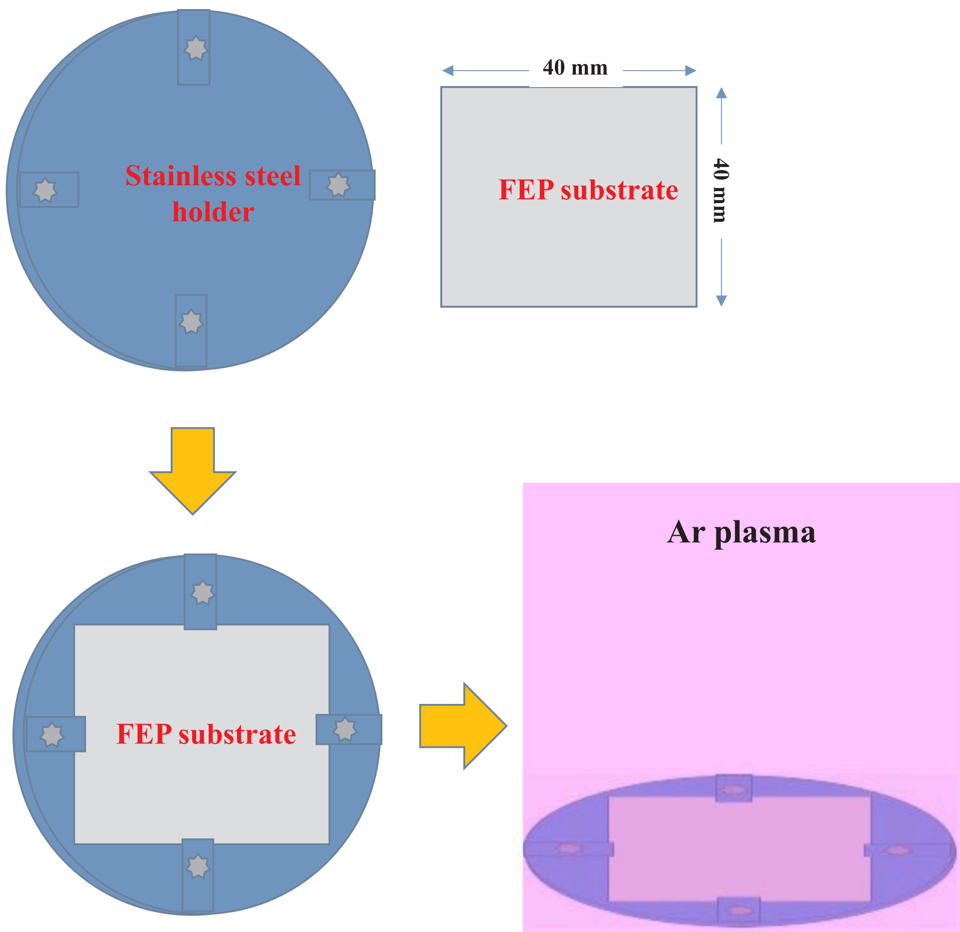

Fig. 1. Schematic representation of FEP plasma etching process.

insulating surface nature. This electrostatic charge (i.e., ~ 20–30 kV) can cause serious damage to the satellite if it is not properly drained away [3,4,16]. To bleed off the accumulated static electric charges the moderate sheet resistance surface is preferred [3,4,15,16]. Indium tin oxide film (ITO) is often utilized on FEP and Kapton® to bleed off electrostatic charges for space application. Apart from electrical conductivity the ITO thin film also shows highly transparent behavior in solar region of the spectrum and thus optical properties of the substrate (with rear surface reflective coating) are not hindered.

High quality ITO thin film with good uniformity, low impurity level and good adhesion to the substrates can be prepared by sputtering [12,17–20]. Reactive sputtering of highly transparent, conducting and adherent ITO thin films on polymer substrates from an In:Sn alloy target requires precise optimization of deposition parameters such as oxygen and argon flow rates, substrate temperature, film thickness, etc. [17–19,21–26]. Moreover, the polymer substrates like FEP have low melting temperature (240 °C), therefore, the substrate temperature cannot be kept very high which is usually required for the deposition of high quality ITO thin films (i.e., T_s > 350 °C) [27].

The stability of ITO coating on FEP and Kapton® substrates in extreme space environments and at launch condition is a main concern [2–4,28]. It has been reported that, achieving good adhesion of ITO thin film on FEP substrate is a difficult task; the sheet resistance of ITO coating on these substrate is likely to increase in space environment due to the delamination of ITO film from the substrate [3,29]. Hence, it is important to examine the stability of ITO coated FEP and Kapton® substrates in simulated space environments and at the prelaunch conditions.

In the present work we describe the evaluation of sheet resistance and thermo-optical properties of ITO coated FEP, Kapton® and aluminized Kapton® substrates before and after environmental tests. Environmental tests such as: relative humidity (RH), thermal cycling (TC) and thermo-vacuum (TVAC) were performed in simulated space environments. To improve the adhesion of ITO coating on FEP substrate, plasma etching was carried out in argon plasma prior to the ITO deposition.

2. Experimental procedure

ITO thin films were sputtered using a reactive balanced magnetron sputtering system in $Ar + O_2$ plasma using pulsed DC power supply. An In (90%):Sn (10%) alloy target of 99.99% purity with 3 in. diameter was used for the ITO deposition. ITO film deposition was carried out at a substrate temperature of 140 °C which is safe for the FEP substrate having an operating temperature of 200 °C. Dupont™ Teflon® FEP (type A, ~ 125 µm thickness), plain Kapton® and aluminized Kapton® (thickness ~ 50 µm) of size 4 cm × 4 cm were used as the substrates. FEP and plain Kapton® substrates were ultrasonically cleaned in isopropyl alcohol for 2 min and dried with high purity nitrogen flush before placing into the vacuum chamber. The aluminized Kapton® substrates were not cleaned in any chemicals and they were loaded into the vacuum chamber as it is after nitrogen flushing. ITO was deposited on the opposite side of aluminium coated side of Kapton® substrate.

The solar transmittance and reflectance of the samples were recorded using a PerkinElmer Lambda 950 UV–Vis–NIR spectrophotometer. Average transmittance ($T_{av.}$) of the samples was measured using a solar spectrum reflectometer of M/s. Devices and Services (Model SSR). Solar spectrum emissometer from M/s. Devices and Services (Model AE) was used to measure the IR emittance. Sheet resistance was measured using a four-point probe (Jandal 3000 Instrument). Field emission scanning electron microscope (FESEM, Carl Zeiss Supra 40VP) was used to study the surface morphology of the